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A new method of measuring the adoption of soil conservation practices; theory and applications

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Abstract

This paper presents a new methodology for measuring the adoption of sustainable agricultural practices that attempts to integrate positive features of earlier approaches. It measures the degree of sustainability observed by the farmer and, at the same time, is straightforward and efficient in field-by-field appraisals. The methodology proposed starts with the identification of all available soil conservation practices in the area. The practices are then grouped into activity categories and are ranked within each category on the basis of their expected soil conservation effect on the plot system. The resulting ranking system is applied to each plot included in the analysis. Non-linear principal component analysis is carried out on the plot rankings to extract a limited number of major metric components.

The method is applied to the Cabuyal watershed in Colombia. The analysis shows that soil management strategies of Cabuyal farmers consist of different combinations of basic soil conservation practices: soil disturbance control, soil protection practices and run-off control. A cluster analysis of the plot scores on these three combinations revealed that the different strategies of soil management are related to the institutional, economic, physical and personal-social factors affecting farms and farmers. The results from the cluster analysis show the usefulness of the proposed methodology for policy purposes.

Additional keywords: measuring soil sustainability, non-linear principal component analysis, soil conservation strategies, cluster analysis

Introduction

Soil erosion is widely recognized as an important agricultural problem in developing countries. Policies proposed by industry and governments to improve soil sustainability should be based on in-depth knowledge of the nature and scope of this problem. This requires effective and efficient methods to measure soil sustainability.

Methods used in earlier approaches to appraise soil sustainability are either too general regarding the actual adoption process (e.g. adoption versus non-adoption) but straightforward enough to be undertaken in field-by-field studies, or too detailed (e.g. degree of sustainability) and very data demanding but more suitable for 'single-farm' studies.

This paper describes a new methodology for measuring farm soil sustainability. The methodology attempts to integrate positive features of both types of approach by measuring the degree of sustainability observed by the farmer while, at the same time, being straightforward and efficient in field-by-field appraisals. As an illustration, the method is applied to a small-farm Andean hillside area: the Cabuyal watershed in Colombia. The methodology, it is believed, contributes to the empirical appraisal of soil sustainability.

The paper is organized as follows. First, important contributions to the measurement of soil sustainability are reviewed. Next, a new method of measuring the adoption of soil sustainability practices is proposed. Its usefulness for policy purposes is illustrated by a cluster analysis of farms on the basis of their adoption of soil sustainability practices and the characteristics of the extracted farm clusters. The paper closes with a discussion of the results and some general conclusions.

Earlier attempts to measure soil sustainability

Despite several attempts in recent years to quantify the concept of soil sustainability, there is still no blueprint for its assessment (Harrington, 1992; Mazzucato & Niemeijer, 2000). In some approaches *state variables* or *control variables* are quantified. State variables describe the quality of the environment or specific resources (e.g. depth of soil remaining after erosion), while control variables directly influence the level of a state variable (e.g. tillage practice). Table 1 lists some of the most common approaches to measuring soil sustainability.

Appraisal approaches range from proxies that determine whether farmers use soil conservation practices, to criteria that estimate in a detailed manner the inversion in land improvement or the magnitude of nutrients exported or of soil lost. The variables involved in the measurement of sustainability are either nominal variables that indicate whether a producer is an adopter or a non-adopter, or continuous variables that attempt to reflect the degree of (un)sustainability (e.g. level of erosion or soil nutrient losses). Nominal approaches are uncomplicated to undertake and very flexible in field-by-field studies, but they ignore the degree of adoption of a sustainable practice by farmers. Nominal approaches lack a large part of the insight into the adoption process and they narrow down the options for the use of quantitative analysis aimed at the detection of cause-effect relationships. Continuous approaches are more precise in the appreciation of the degree of sustainability, but they are more complex to implement and data intensive. Also, it should be noted that many in-depth studies have been made of the impact of specific soil conservation measures, such as tillage practices (Biamah *et al.*, 2000), stone rows (De Graaff, 2001), earth bunds and vegetation barriers (De Graaff & Spaan, 2002).

Table 1. Approaches to measuring soil sustainability.

Approach	Description	Strengths	Drawbacks
Dichotomous (e.g. Harper *et al.*, 1990; D'Souza *et al.*, 1993; Mbaga, 1998)	Adoption/non-adoption of sustainable agricultural practices.	Simple and flexible in cross-sectional studies.	Ignores the degree to which adoption is made.
No. of practices index (e.g. Ervin & Ervin, 1982)	Adds up to the number of conservation practices.	Ditto	Practices are equally weighted regardless of their relevance.
Trends in ouput and yields (TOY) (e.g. Harrington, 1992)	Analysis of trends in production and/or yields. Declines imply possible degradation.	Suitable for case-specific studies.	Sustainability problems can also be present with rising yield trends.
Trends in per capita production (TCP) (e.g. Monteith, 1992)	Declining trends in per capita production (inputs held constant) stand for sustainability problems.	Precise, and suitable for case-specific studies.	Data demanding and mainly for enterprise-specific analysis, such as control trials.
Total factor productivity (TFP) (e.g. Lynam & Herdit, 1989; Cardwell, 1982; Byerlee & Siddiq, 1994)	Ratio of output and inputs. A sustainable system would feature a constant/positive trend.	Suitable for case-specific studies.	Data demanding, enterprise-specific and and ambiguous: a declining trend might also be due to declining product prices and higher input prices.
TFP revisited (e.g. Samuelson & Nordhaus, 1998)	Defined as the residual after accounting for the effects of increased input levels on output.	Ditto	Confounds the positive effects of technological changes and the negative effects of resource degradation.
Nutrient flow balance (e.g. Pieri, 1989; Van Keulen, 1993; Van Der Pol, 1992; Smaling, 1993; Van Duivenboden & Van Veeneklaas, 1992)	Monetary value of the difference between plant nutrients exported from cultivated fields and those added or imported.	Precise, and enables monetary evaluation of nutrient depletion.	Data demanding and enterprise-specific.
Land investment (e.g. Carlson *et al.*, 1993; Norris & Batie, 1987; Saliba & Bromley, 1986)	Investment (in capital) in land improvement.	Precise, and suitable for case-specific studies.	Demanding on data of total capital expenditures, annual operation and maintenance expenses.
Soil loss (e.g. El-Swaify & Dangler, 1976; Saliba & Bromley, 1986; Reining, 1992)	The 'Universal Soil Loss Equation' (USLE) (Wischmeier & Smith, 1978)	Ditto	Requires the set up of field trials appropriately equipped with soil-collecting canals.
Conservation effort (e.g. Ervin & Ervin, 1982)	Difference between the USLE with and without conservation practices.	A proxy to 'land investment' when capital expenditure data are not available.	Earlier information on farm erosion without conservation practices often absent.

A new method of measuring the adoption of sustainable agricultural practices (ASAP)

The proposed method of measuring the adoption of sustainable agricultural practices (ASAP) with respect to soil erosion attempts to integrate the positive features of the existing nominal and continuous measures. (In this definition of ASAP, 'adoption' is referring to all practices being adopted and still in use at present.) It combines the capacity to distinguish different degrees of sustainability while appraising soil sustainability efficiently on a field-by-field basis. It is operationalized as the number of adopted sustainable agricultural practices weighted by their relevance for the soil conservation problem at hand. As a result, the more pertinent the sustainable practices, the greater the measured degree of soil sustainability observed by the farmer.

The steps involved in the proposed method are portrayed in Figure 1. In the first step, the soil conservation practices are identified and grouped into different categories according to farm activity. Obviously, these practices will depend on the region and on the type of farming under consideration. In the second step, the practices are subjected to a ranking of effectiveness within each category and applied to each farm plot included in the analysis. The validity of this ranking of soil conservation measures in empirical research hinges on the quality of the ranking expert, which will be illustrated in the application of ASAP to the Cabuyal watershed. In the third step, non-linear principal component analysis (NPCA) is carried out on the plots' rankings in order to extract a limited number of major metric components. The extracted components represent basic dimensions of soil sustainability adoption. The scores of the plots on these dimensions can then be determined. We thus propose a

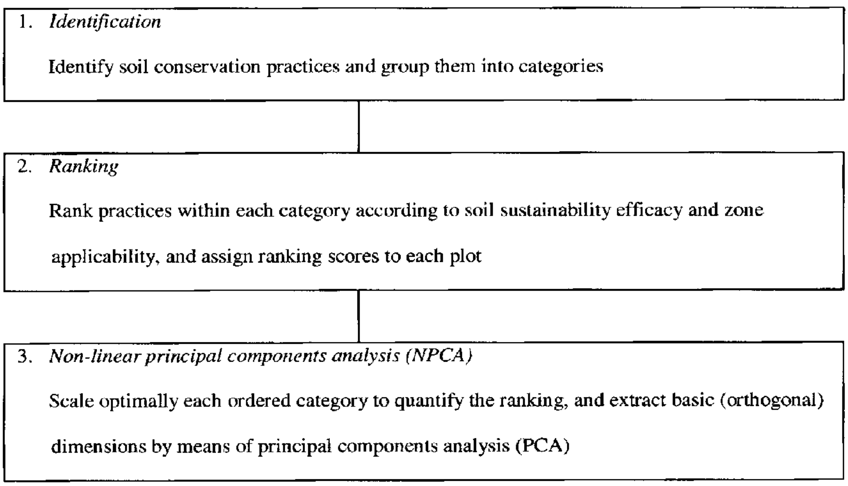

Figure 1. Steps involved in the proposed method to measure the adoption of sustainable agricultural practices (ASAP).

comprehensive measure of agricultural soil conservation, which can be used for policy purposes. The cluster analysis illustrates this point.

An application of ASAP to the Cabuyal watershed, Colombia

Soil conservation problems in the Cabuyal watershed

In tropical hillside agricultural zones in Central and South America, small farmers occupy the least fertile and most easily destroyed sloping land. In this type of terrain, soil depletion rates are higher than restoration rates (Anon., 1993; 1996). Unequal land distribution together with a poor market infrastructure puts pressure on farmers to exploit the resource base to meet their sustenance needs.

The Cabuyal watershed, a tropical hillside area in Colombia (Figure 2), was selected for a case study. The site shares not only the typical characteristics of bio-diversity of tropical hillsides, but also most of the problems related to high population density, lack of physical infrastructure and severe erosion. The Cabuyal soils are fragile, acid and of low fertility, and the landscapes are craggy. The fragility of the region has been challenged by an over-intensified use of the land. Over time, farming in the watershed has been characterized by shorter fallow periods, more intensive cultivation of annual crops and the extension of cropping into steeper and more marginal areas (Amézquita *et al.*, 1998). Crops such as cassava, kidney beans and maize have been cultivated on slopes without erosion control practices, leading to severe

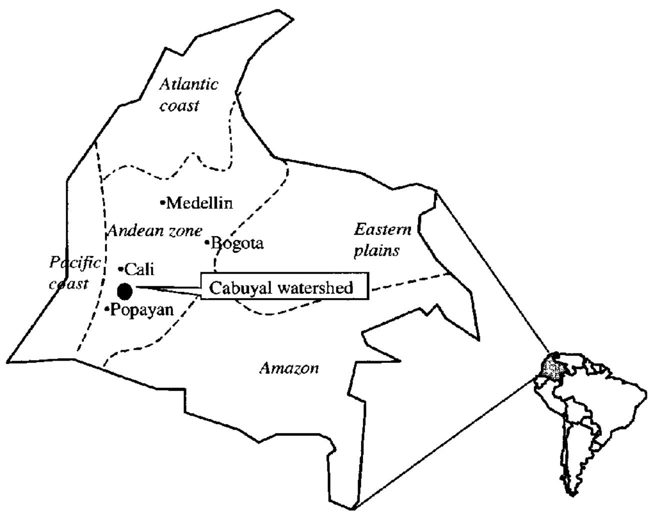

Figure 2. Location of the Cabuyal watershed, Colombia, South America.

Table 2. Description of the Cabuyal watershed.

Area (ha)	7525
Altitude (m)	1175–2200
Annual rainfall (mm)	1700
Topography (%)	15 (slopes < 12%); 36 (slopes 12–30%); 49 (slopes > 30%)
Soil characteristics	Acidic (pH 5–6), infertile Inceptisols (high S, low P)
Conservation problems	Erosion (slope cropping), deforestation
No. of farms	1135
Illiteracy (%)	29
Land owners (%)	77
Average farm area (ha)	3
Products and main uses	Cassava (sold on farm for starch production); coffee, kidney beans (sold at town market); maize (own consumption); plantain (own consumption and sold on farm)

soil losses and a decrease in soil fertility (Reining, 1992). The potential for soil erosion is especially high during the months prior and subsequent to planting, as the soil is then exposed to intensive tropical rainfall (Reining, 1992; Howeler & Cadavid, 1981). Research has shown that up to 80% of the annual soil losses can occur in a single rainstorm (Ruppenthal, 1995). Nonetheless, the Cabuyal soils have an excellent structural stability and high infiltration rate and still possess the potential of agricultural production once soil erosion and fertility constraints can be alleviated. For further information on the Cabuyal watershed see Table 2 and Castaño (2001).

The response of the government to soil degradation in Cabuyal has been marginal, and is mainly canalized through crop diversification campaigns of the Coffee Growers Federation. Local NGOs and other institutions involved in research activities in Cabuyal have been promoting the use of soil conservation practices but with modest results. Some institutions conditioned credit for the adoption of live barriers, such as pastures, which are very effective in soil erosion control. Although initially adopted, farmers abandoned the practices because the pastures either did not have other uses, such as fodder production for animals, or they demanded too much effort and space. Other institutions have had better results by organizing field trips in which farmers could observe other farmers' trials.

Since the 1980s, Cabuyal has been one of the pilot study sites of the International Center for Tropical Agriculture (CIAT) for the purpose of assessing participatory solutions to tropical America hillside agriculture's low income and soil conservation problems (Amézquita *et al.*, 1998). Cabuyal hillside farmers face a fertility management choice as soil losses and loss of precious topsoil (the nutrient layer) are the dominant soil conservation problems (Anon., 1982; 1998; Reining, 1992). Although the acceptable amount of yearly soil loss in Cabuyal has been estimated at 1–5 t ha^{-1} (Reining, 1992), research by CIAT has shown that soil losses of 100 t ha^{-1} or more can occur over a period of 10 months, which is about 5% of the top soil (Howeler, 1985). This means that even on gentle slopes all fertile soil of permanently bare fallow plots may be lost within a decade (Ruppenthal, 1995).

The analysis of soil conservation practices in Cabuyal

In Cabuyal a survey was undertaken of a random sample of 120 farms (10% of the watershed farms). The survey consisted of two parts. Part one characterized the households and examined farmers' soil conservation management in the most or two most important plots of the farm, while part two examined their access to institutions and marketing services. In all, information from 196 farm plots was collected in the survey. Below we will discuss the three steps involved in the proposed ASAP method using the survey data.

Step 1. Identifying and grouping soil conservation practices
Farmers in Cabuyal adopt soil conservation measures primarily to reduce the negative impact of soil erosion and the losses of water, nutrients, and organic matter associated with it (Anon., 1998; Castaño, 2001). Soil conservation measures in Cabuyal comprise (1) practices intended to protect the soil against the impact of raindrops (e.g. plant cover, mulching), (2) practices that reduce surface run-off and increase water infiltration (e.g. live barriers, interception drains), (3) practices intended to maintain soil fertility (e.g. animal manure), and (4) practices that have little negative impact on the physical properties of the soil (e.g. minimum tillage). These practices are listed in Table 3, both individually and in various combinations. The practices were grouped into seven categories according to farm activities: soil conditioning, soil preparation, planting, fertilizing, weeding, harvesting, and run-off control.

Step 2. Ranking soil conservation practices
Each practice was ranked according to the expected soil conservation effect within its category. The ranking was undertaken with the assistance of CIAT's soil scientists who are intimately acquainted with the region's agriculture, and on the basis of CIAT's extensive research on Cabuyal's crop and soil management (Howeler & Cadavid, 1981; Howeler, 1985; Howeler & Ezumah, 1993; Ashby, 1985; Reining, 1992; Castillo, 1994; Ruppenthal, 1995; Claros, 2002). The discussion below is largely based on the results of this research and the criteria for the assignment of ranks are specifically pertinent to the regional farm practices.

Live barriers are rows of perennial plants of dense growth that Cabuyal farmers plant perpendicular to the slope, on the contour, between the crops. They are used to minimize soil loss during heavy rains (Claros, 2002). Live barriers not only reduce the rate of run-off but also act as live filters, trapping the sediment carried by the run-off water. They also improve soil fertility, as fallen leaves and other crop residues trapped by the barriers are gradually decomposed and their nutrients released into the soil.

Live barriers were ranked according to their expected role in soil erosion control and layout (barrier distances and number of furrows). Compared with other live barriers, elephant and king grass are rigid, dense and deeply-rooted clump grasses that bind the soil, forming green hedges capable of trapping crop residues and silt eroded by run-off, which enables them to naturally form an earth embankment (Müller-Sämann *et al.*, 1994; Claros, 2002). Ruppenthal (1995) found that elephant grass barriers significantly reduced soil loss in Cabuyal.

Mulch consists of crop residues and other organic matter that is piled up on the plot contours as a dead barrier and serves both as a trapping wall for soil and as a source of soil nutrients and fertilizer (Anon., 1998).

Strips of *Arachis pintoi* and *Brachiaria decumbens* reduce the velocity of the surface flow, which can lead to sedimentation of detached particles (Wischmeier & Smith, 1978). Barriers that are more useful for plot-boundary demarcation (*Trichanthera gigante*) or home consumption (pineapple and *Inga densiflora*) (Müller-Sämann *et al.*, 1994) received a lower ranking.

Tillage affects soil structure, water-holding capacity, aeration, infiltration capacity, soil temperature and evaporation (Reijntjes *et al.*, 1992). In Cabuyal, tillage is carried out by hand or with an ox-plough (Castaño, 2001). Reining (1992) and Ruppenthal (1995) concluded that compared with conventional tillage with ox-ploughs, minimum tillage practices, only making planting holes, reduce soil loss and run-off and thus are ranked higher. Full tillage practices such as ox-ploughing loosen the soil leaving the thin topsoil layer more prone to soil loss and degradation, especially on steep slopes and during rainfall before crop establishment. Moreover, a constant depth of tillage can lead to soil compaction, reduced permeability and biological degradation. During land clearing most Cabuyal farmers slash the shrub and burn it. Practices that involve the incorporation of part of the slashed shrub into the exposed soil as cover and mulch are included in the ranking.

Planting is very much related to the crop. Coffee is transplanted into holes dug during land preparation. Maize and kidney beans are planted in rows or with the aid of a digging stick (Castaño, 2001). With row planting ('chorrillo') the seeds are manually scattered in furrows previously loosened by hoe, while with stick planting 2 or 3 seeds are placed in shallow holes made with a pointed iron stick ('barreton'). Cassava planting material consists of cuttings, which are planted in holes. Transplanting coffee and planting cassava result in reduced soil loss and run-off (Reining, 1992), while row planting and stick planting imply an additional physical impact on soil structure.

In Cabuyal, where soils are acid and soil fertility is low, the use of organic fertilizers such as compost, crop residues and animal manure is ranked higher than sole chemical fertilization (Reijntjes *et al.*, 1992). Apart from an increase in fertility, organic fertilization also provides earlier ground cover. Compost is important for recycling organic waste. It is a slow-release organic fertilizer that stimulates soil life, improves soil structure and enhances crop yields. Crop residues form an important shallow layer that not only increases soil fertility through gradual release of nutrients but also improves the soil microclimate, enhances soil life, improves water infiltration, conserves soil moisture and prevents damage from solar radiation and rainfall. The layer of residues reduces the splash effect of raindrops significantly and prevents the disintegration of soil aggregates (Ricaurte *et al.*, 2000). Animal manures help improve soil structure, are rich in nutrients, especially nitrogen, a key nutrient for leaf and stem growth, but have a low content of phosphorus, an element important for root development. 'Gallinaza', a widely used organic fertilizer in Cabuyal made of chicken manure and lime, is very efficient on acid soils (Castaño, 2001).

Weeding farm plots in Cabuyal is predominantly done manually using a machete, shovel or hoe. Herbicides are rarely used due to their high costs. Selective weeding is a technique directed at the most problematic and damaging weed types in a specific field (Reijntjes *et al.*, 1992). Higher ranks are assigned to weed control practices such as ring weeding that do not target weeds that serve as a natural, living ground cover and do not compete with crop plants (Table 3). Ring weeding ('aporque') is the manual clearing of weeds, using a machete or hoe, around each individual plant. It is usually combined with the piling-up of soil around the base of the plant. Ranks are also higher for machete weeding due to its lower physical impact on soil structure compared with shovel weeding (Howeler & Ezumah, 1993; Reijntjes *et al.*, 1992).

Like soil preparation and planting practices, harvesting practices are associated with crop and production systems. Picking is practised with coffee and kidney beans, grain harvesting with maize and root harvesting with cassava and kidney beans. With kidney beans the entire plant is pulled up and left to dry in the field before being threshed. In terms of soil conservation, picking and grain harvesting have a lower impact on the soil and therefore are ranked higher than root harvesting (Howeler & Cadavid, 1981). The pulling-up of cassava roots loosens the soil, leaving the bare ground prone to soil and nutrient losses until a new cover has been established, either by weeds and shrubs or by a new crop (Ruppenthal, 1995).

Finally, waterways at the plot borders and interception drains are helpful measures to divert water flows out of the farm plot and prevent water erosion and the loss of soil and nutrients. In Cabuyal larger amounts of nutrients are lost by run-off than by soil loss (Reining, 1992). Ranks were assigned when any of these labour-intensive physical structures was implemented to reduce run-off and nutrient depletion.

Table 3 shows the practices (individually and in combinations) ranked according to the criteria presented above. Practices are mutually exclusive within each category (i.e. only one score per practice). Ties among practices were averaged as is customary in ranking procedures. For example, the top four of the 16 soil conditioning practices were ranked equally. So an average value of 14.5 [i.e., (16+15+14+13)/4] was assigned to each. The ranking system was subsequently applied to each of the 196 plots on the basis of whether or not the farmer had adopted one or more practices in the seven conservation categories. Consequently, seven ordinal variables were obtained, each corresponding to a soil conservation category.

The ordinal nature of the variables sets limitations for statistical analysis. For instance, it would be inaccurate to argue that digging holes during field preparation (ranked 8) is twice as sustainable as preparing a field with an ox-plough (ranked 4). There might also be a relationship between categories, implying some degree of redundancy. The final step of the method removes these limitations by extracting a few essential metric components from the ordinal variables.

Step 3. Non-linear principal component analysis

The components that form the basis of ASAP can be identified by means of principal component analysis (PCA). PCA consists of finding relationships among given metric attributes and representing these relationships in a few independent components (dimensions). These components account for part of the original variance and

Table 3. Ranking[1] of the soil conservation practices in Cabuyal grouped in 7 soil conservation categories. Rankings based on experts' judgements.

Soil conditioning		Soil preparation		Planting[2]		Fertilizing	
Elephant grass[3]	14.5	Digging new field	9	(Trans)planting	3	Residues + chicken manure + compost + chemicals	15.5
King grass[4]	14.5	Digging + hoe	8	Row planting	1.5	Residues + chicken manure + cow dung + chemicals	15.5
Mulch	14.5	Digging stubbly field	7	Stick planting	1.5	Residues + chicken manure + chemicals	10.5
Iraca[5]	14.5	Iron stick	6			Residues + compost + chemicals	10.5
Citronella/lemon grass[6]	11	Slash-and-mulch	4			Chicken manure + compost + chemicals	10.5
Sisal[7]	11	Slash and partial mulch	4			Chicken manure + compost	10.5
Axonopus micay	11	Ox-ploughing new field	4			Residues + compost	10.5
Telembi[8]/imperial	7.5	Liming	2			Chicken manure + residues	10.5
Arachis pintoi	7.5	Ox-ploughing stubbly field	1			Compost	10.5
Centrosema acutifolium	7.5					Residues	10.5
Brachiaria decumbens	7.5					Cow dung	4.5
Sugar cane	4.5					Chicken manure	4.5
Trichanthera gigante	4.5					Chicken manure + chemicals	4.5
Pineapple	2.5					Residues + chemicals	4.5
Inga densiflora	2.5					Chemicals	2
None	1					None	1

Weeding		Harvesting		Run-off control	
Machete	4.5	Picking	6	Waterways	2.5
Ring weeding	4.5	Picking + grain harvest	5	Interception drains	2.5
Shovel + ring weeding	2.5	Grain harvest	4	None	1
Machete + hoe	2.5	Picking + uprooting	3		
Hoe	1	Grain harvest + uprooting	1.5		
		Uprooting	1.5		

[1] The higher the ranking the more effective the practice.
[2] Stripcropping was found in all plots, and is therefore not included.
[3] *Pennisetum purpureum.*
[4] *Saccharum sinense.*
[5] *Carludovica palmata.*
[6] *Cymbopogon nardus/C. citratus.*
[7] *Agave sisalana.*
[8] *Axonopus scoparius.*

assign scores to each observation (object scores) with a zero mean and unit variance. PCA assumes, however, that all variables in the analysis are measured at the numerical level and that relationships between pairs of variables are linear. Non-linear principal component analysis (NPCA) (Gifi, 1990) extends this methodology so that PCA can be applied to any mix of nominal, ordinal, interval and ratio variables. NPCA transforms such a mix of variables into metric variables, looks for non-linear relationships between the variables and reduces the relationships to a few components. NPCA makes use of optimal scaling (Kruskal & Shepard, 1974; Young *et al.*, 1978) to detect non-linear relationships between categorical variables and transforms them into metric variables. Optimal scaling is a technique used to quantitatively transform categorical attributes in order to meet continuity requirements of statistical techniques such as PCA.

Non-linear principal component analysis was carried out by using the SPSS procedure PRINCALS (Anon., 1990). Three components (sustainability components) were obtained out of the seven soil conservation categories identified in Cabuyal (Table 4). The *scree test criterion* was applied to determine the number of components (Hair *et al.*, 1995). Component loadings range from –1 to 1 to indicate the weight of each variable with respect to each component. A component with a large coefficient (absolute value) for a particular variable is closely related to that variable. The component loadings were orthogonally rotated to permit independence among the components and a clearer interpretation. Table 4 lists the results of the NPCA of the sustainability rankings of the 196 plots. The various planting practices do not appear to differ much in their conservation effect on the soil resulting in no meaningful contribution to the explained variance.

The sustainability components account for a significant proportion of the original variance (68.4%). The three extracted components can be interpreted on the basis of the categories with high loadings on that component.

Component 1 refers to farm activities associated with the crop and production process. They include practices such as soil preparation by hand or with oxen-traction, slash-and-mulch and root or grain harvesting, which are related to soil conser-

Table 4. Results of applying non-linear principal component analysis (NPCA) on rankings of soil conservation practices for 196 plots in Cabuyal[1].

Soil conservation practice	Component 1[2]	Component 2	Component 3
Conditioning	–0.016	**0.714**	–0.071
Preparation	**0.884**	–0.070	0.073
Planting	0.220	–0.010	0.005
Fertilizing	–0.180	**0.680**	0.003
Weeding	0.390	**0.571**	–0.148
Harvesting	**0.908**	–0.028	–0.053
Run-off control	0.047	0.116	**0.991**
% of original variance	29.0	22.0	17.4

[1] Component loadings larger than 0.50 (absolute value) are printed in bold.
[2] Component 1: soil disturbance control; component 2: soil protection; component 3: run-off control.

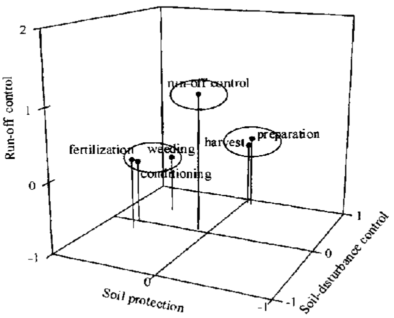

Figure 3. Soil sustainability components extracted by non-linear principal components analysis (NPCA) (see Table 4).

vation practices in soil preparation and crop harvesting. These practices cause physical disturbance of the soil. Soil perturbation affects the size of soil aggregates, the decomposition rate and therefore the loss of organic matter. Organic matter is one of the most important factors for a production system. It determines, to a large extent, recycling of nutrients, soil structural stability and biological activities of micro and macrofauna (micro-organisms, earthworms, etc.). The less disturbed the soil, the greater soil sustainability will be. Component 1 is labelled *soil disturbance control.*

Component 2 comprises practices not related to the crop production process but intended to provide topsoil protection and nutrients through covering and fertilizing practices. They include structural practices such as live barriers, live mulch (e.g. grass) and mulch from weeding and crop residues. Fertilizing provides, besides fertility management, appropriate conditions for the growth of soil-protective covering (Hudson, 1981). These types of protective practices are very important as soil loss in Cabuyal hillsides is attributed more to rainfall erosivity than to soil erodibility (Reining, 1992). A good cover provides protective mulch against the impact of raindrops, decreases soil run-off, increases the input of organic residues, stabilizes soil temperature, and reduces the organic matter decomposition rate. Component 2 is labelled *soil protection practices.*

Component 3 is merely associated with drainage practices. These practices comprise the construction of waterways and interception drains that lead away any concentration of surface water and avoid loss of soil and leaching of nutrients. This component is labelled *run-off control.* Figure 3 depicts the three soil sustainability components in relation to the soil conservation categories.

A cluster analysis of farms on the basis of soil sustainability practices measured by ASAP

To demonstrate the usefulness of the ASAP methodology for policy purposes, a cluster analysis (Anon., 1999) was applied to plot scores on the ASAP components extracted from the Cabuyal data. Since there is a one-to-one relationship between farms and

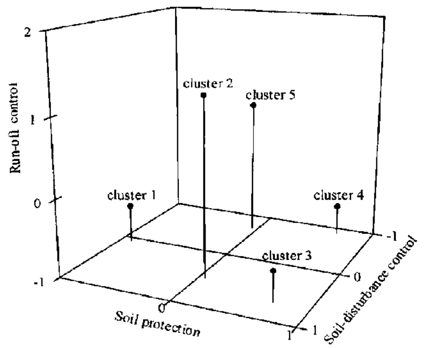

Figure 4. Farm clusters portrayed on the basis of their average scores on soil sustainability components.

plots, a cluster analysis of plots also implies a cluster analysis of farms. In cases where there was more than one plot per farm we used averages of the plot scores per farm.

Cabuyal farmers differ in their strategies towards soil sustainability by applying different combinations of soil disturbance control, soil protection practices and run-off control, which will be revealed by cluster analysis. Such information may be helpful for government, marketing institutions and extension services in their policies aimed at stimulating soil conservation practices.

Cluster analysis of farms identified 5 farm clusters on the basis of the cut-off point of the clusters' R^2 contributions (Hair *et al.*, 1995). Clusters 1 to 5, composed of 32, 28, 26, 17 and 17 small farms, respectively, account for 64% of the total variance. For the average scores for the three soil sustainability components of the farms in these five clusters see Figure 4.

Figure 4 shows that the average values of the scores per soil sustainability component per cluster tend to be either extremely high (i.e. close to 1 or –1) or non-significant (i.e. zero). This means that the clusters can be represented as five soil management strategies, where farm households extensively or to a limited extent use a particular category of soil sustainability practices (Table 5). These five well-differentiated soil management strategies are:

1. *Non-adopters*: farms characterized by not adopting any soil conservation practice whatsoever.

Table 5. Cabuyal soil management strategies[1] of clusters 1 to 5 on the basis of the combination of soil conservation practices used (average scores).

Combination of practices	Clusters of soil management strategies				
	1	2	3	4	5
Soil disturbance control	0.1	0.5	0.7	–0.9	–0.7
Soil protection	–0.9	0.1	0.7	0.7	–0.1
Run-off control	–0.5	1.3	–0.6	–0.6	0.8

[1] For the five clusters of soil management strategies see text.

2. *Adopters of soil disturbance control and run-off control practices*: farms that practice minimum tillage to control soil disturbance and construct interception drains to control run-off.
3. *Adopters of soil disturbance control and protection practices who ignore run-off*: farms that control soil disturbance and protect the topsoil with a mulch cover, but do not practice run-off control.
4. *Adopters of soil protection practices who ignore soil disturbance and run-off*: farms that apply topsoil protection practices, but do not take measures against soil disturbance and run-off.
5. *Adopters of run-off control who ignore soil disturbance*: farms that apply practices to prevent run-off, but do not control soil disturbance.

Governments and marketing institutions wishing to help improve soil sustainability should be aware of the characteristics of the farmers in the various clusters in order to approach these farmers effectively. This point will be elaborated in the next section.

Characteristics of farm clusters practising different soil management strategies

To gain a better insight into soil management in Cabuyal, the soil management strategies were crossed with institutional, personal-social, economic and physical farm characteristics in the Cabuyal region. In our survey these were measured as: (1) *personal characteristics of the farmer*: age, education, risk proneness, ethnic background (indigenous or non-indigenous); (2) *economic characteristics*: farm size, well being (a measure taking into account income, employment capacity, crop diversity, non-agricultural income and housing quality (Ravnborg, 1999)); (3) *institutional characteristics*: access to marketing services and institutions, road access, contracted production, subsidy for pest management, and (4) *physical characteristics*: slope gradient, slope length, soil depth, agro-ecological zone. These characteristics have been selected on the basis of a review of the literature and an analysis of Cabuyal agriculture (Castaño, 2001). The results are summarized in Table 6.

Strategy 1. Non-adopters

The 'non-adopters' strategy is followed by older and poorer farmers (low *well-being* index) with short planning-time frames. Farms tend to be small with a marked preference for coffee growing. Access to institutional services such as credit, inputs and extension is poor. These farmers tend to shy away from risk and innovation. The non-adoption of soil conservation practices is most often seen in smaller plots with shallow soils in the medium-low agro-ecological zone of the watershed.

Strategy 2. Adopters of soil disturbance control and run-off control practices

This cluster is made up of poorer coffee growers with longer planning-time frames.

Table 6. Average values of farm characteristics in the 5 clusters differing in soil sustainability strategies[1].

Farm characteristic	Cluster of soil management strategies				
	1	2	3	4	5
Personal-social					
Age of farmer (years)	50	46	50	47	42
Education level (years)	2.5	2.3	2.2	3.1	2.3
Risk prone/innovativeness	low	average	high	high	low
Non-indigenous farmers (%)	84	71	73	94	67
Economic					
Farm size (ha)	2.7	3.7	3.1	5.0	3.2
Well-being (% farmers above average)[2]	22	21	31	29	33
Owners (%)	100	96	100	94	100
Predominant crop	coffee	coffee	coffee	kidney beans, coffee, other[3]	cassava
Long-term planners	no	yes	yes	yes	no
Farm labour (men per farm)	2.8	3.6	2.8	2.2	2.9
Institutional					
Access to marketing services, institutions	poor	average	average	good	average
Good road access (% of farmers)	38	50	54	59	17
Contracted production (% of farmers)	28	18	12	41	50
Subsidy for coffee pest management (%)	19	11	27	29	11
Physical					
Slope gradient	mild	steep	mild	gentle	mild
Slope length (m)	65	66	69	75	66
Soil depth (cm)	17	21	24	27	19
Agro-ecological zone	low, medium	medium	medium	medium	high

[1] For the five clusters of soil management strategies see text.
[2] The farmers' *well-being* is an index that attempts to reveal welfare differences among farmers.
[3] Includes intercrops of cassava and maize. Coffee is intercropped with plantain.

These farm households tend to have more labour available than on average, which may be very helpful for the implementation of soil conservation measures. A significant number of these farmers are ethnic Indians. Their access to marketing services and institutions is average but access to coffee-related subsidies is comparatively poorer. This group of adopters seems to reside most frequently in the steepest areas of the medium agro-ecological zone.

Strategy 3. Adopters of soil disturbance control and soil protection practices who ignore run-off

This strategy is embraced by older and less educated farmers, many of whom are of indigenous origin. The farmers are coffee growers with long planning horizons. They have above-average access to markets, market institutions and market services, but tend to shy away from contract production. A significant number of these farmers benefited from subsidies for coffee pest management. This group of adopters resides in the medium agro-ecological zone.

Strategy 4. Adopters of soil protection practices who ignore soil disturbance and run-off

The followers of this strategy seem to be most influenced by institutional, personal, economic and physical factors. The group is comprised of more educated non-indigenous farmers who are very innovative in trying new farming practices and do not shy away from risky situations. These farmers are wealthier and own farms of above-average size with diversified cropping systems. They tend to have long-term planning attitudes and undertake soil protection practices despite sufficient farm labour. The farmers tend to have good access to markets, institutions and marketing services, and about one-third of them have been granted subsidies for coffee pest management. Contractual production is a frequent practice. The adoption of topsoil protection practices tends to be more frequent in large fields with gentle slopes and thick topsoil in the medium agro-ecological zone.

Strategy 5. Adopters of soil run-off control who ignore soil disturbance

The fifth soil management strategy is adopted by younger cassava growers. A significant number of farmers are ethnic Indians and tend to be risk averse. They have an above-average well-being level but they are concerned about debts. Despite contractual arrangements with cassava starch processors, these farmers have bad road access to the market. Access to institutions and, thereby, to marketing services is average while access to coffee-related subsidies is poorer. Run-off control measures seem to be more commonly adopted for shallow soils in the highest agro-ecological zone.

The differences between the five extracted clusters offer guidance for sustainability policies. For instance, policies aiming at improving soil sustainability of coffee growers should take into account the differences between clusters 1, 2 and 3 in both the applied soil conservation practices and risk proneness/innovativeness.

Discussion

The foregoing analysis improves our understanding of soil conservation practices in Cabuyal. Firstly, the analysis shows that the soil management strategies of Cabuyal farmers consist of different combinations of basic soil conservation practices: soil disturbance control, soil protection practices and run-off control. The strategies vary from limited use to extensive use of practices in up to two of the three combinations of identified basic soil conservation methods. Secondly, non-adopters are mainly older and poorer farmers with limited access to market services. Thirdly, adoption of soil protection practices (strategies 3 and, in particular, 4) appears to be the most important soil conservation procedure in Cabuyal. Topsoil protection is crucial as water erosion is extremely critical during crop planting and after harvesting, when the topsoil is often left exposed. The farmers applying this type of conservation practice tend to be non-indigenous wealthier farmers who have good access to markets and market services, and who are long-term planners and innovative. In fact, some soil protection practices, such as live barriers, are long-term investments in soil conservation, which can be better met by wealthier farmers. Other soil protection measures, such as mulching and weeding, are practices that are related to the cropping system and do not require capital but labour, which is abundant in Cabuyal. Fourthly, simultaneous adoption of soil protection practices and run-off control did not take place in any of the identified soil management strategies. This suggests that farmers who make use of mulch and live barriers and who utilize other types of topsoil protection practices believe that these practices are also an effective solution for soil run-off and *vice versa*. There is, in this case, a need to explain to farmers the differences between topsoil erosion caused by rainfall and nutrient losses caused by surface water streaming down the field.

Finally, it is stressed that soil conservation practices are only one element of the agricultural production process, implying that policies aiming at improving soil sustainability have to be placed in the context of total farm management (see e.g. Mazzucato & Niemeijer, 2000).

Conclusion

The proposed method to measure the adoption of sustainable agricultural practices with respect to soil erosion (ASAP) appears to be easily applicable in quantitative research. On the one hand the method is *comprehensive* because it includes all relevant soil conservation practices, but on the other hand *manageable* because it reduces the numerous practices to a limited number of basic components of farmers' soil conservation. So the proposed methodology is attractive for policy makers and agricultural service institutions whose policies have to focus on basic sustainability issues and who have to segment their policies with respect to farm type and soil conservation problems.

The application of the proposed method to 196 farm plots of the Cabuyal watershed in Colombia demonstrated the usefulness of interpreting soil sustainability as a multidimensional concept entailing various aspects of the adoption of soil conservation practices.

A cluster analysis of the plot scores on the extracted dimensions enabled the identification of different strategies of soil management, which were related to institutional, economic, physical and personal-social factors of farms. Moreover, these results demonstrate the usefulness of the proposed methodology for gaining insights into soil conservation adoption processes.

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